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STREAK CAMERA MEASUREMENTS OF LASER PULSE TEMPORAL DISPERSION IN SHORT GRADED-INDEX OPTICAL FIBERS*

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A B S T R A C T

Streak camera measurements were used to de.ermine temporal dispersion in short (5 to 30 meter) graded-index optical fibers. Res:lts show that 50-ps, 1.06-μm and 0.53-μm laser pulses can be prop.gated without significant dispersion when care is taken to prevent ,r.opagation of energy in fiber cladding modes.

1. Introduction

Several laser-fusion applications require that a laser pulse be transmitted with minimum temporal distortion through a short length of optical fiber to a wide bandwidth detector. In one measurement, it is desirable to determine the temporal relationships between the laser energy incident on a target, the laser energy scattered from the target, and the target emitted x rays.[1] We have demonstrated that an S-1 optical streak camera[2] can simultaneously record 1.06-μm and x-ray signals. The experimental configuration required to observe target x rays makes it difficult to use mirrors to direct a portion of the incident laser beam onto the streak camera input slit. One method to couple incident laser light into the streak camera is with a short (5 to 10 meter) optical fiber.

The important fiber characteristics for this application are the temporal dispersion and power handling capacity at the laser wavelength. Two types of fibers are designed to minimize pulse dispersion.[3] Single mode fibers have small core diameters to limit the number of modes that propagate. Graded-index fibers use a radial variation in the index of refraction to match the group velocities of the modes that propagate. The streak camera requires several nanojoules of 1.06-μm energy in a 50-ps pulse to produce a detectable signal. For a 4-μm diameter single mode fiber, an average power density greater than 10^9 watts/cm^2 is required. About 10^7 watts/cm^2 is needed for a 50-μm diameter graded-index fiber. Since damage thresholds are around 10^9 watts/cm^2, we elected to use graded-index fibers to interface the incident laser light into the streak camera.

We studied laser pulse dispersion caused by passage through short lengths of optical fiber with a 10-ps resolution streak camera system. The following paragraphs describe measurements of short duration (less than 50-ps) 1.06-μm and frequency doubled 0.53-μm laser pulses transmitted through several samples of graded-index optical fiber.

II. Experimental Setup

Figure 1 shows the experimental setup. The nominal 50-ps laser pulse is obtained by selecting a single 1.06-µm pulse from a passively mode-locked Nd:YAG laser oscillator pulse train. A slightly shorter duration 0.53-µm laser pulse is obtained by passing the laser pulse through a frequency doubling KDP crystal. A small portion of the laser beam is used to trigger the readout electronics. The rest of the laser energy is divided into two parts. One part passes through neutral density and band pass filters, a lensing system, and the optical fiber under test to a segment of a streak camera input slit. For comparison, the remaining laser energy is directed through neutral density and band pass filters, then along an air path of appropriate length to an adjacent area of the input slit and simultaneously recorded.

The light passing through the slit is imaged onto the streak camera[2] photocathode. The resulting photoelectrons are focussed into an electron beam that passes between deflection plates and is imaged onto a phosphor screen. The beam is deflected across the screen to provide a position modulated intensity that corresponds to the time variation of the light intensity on the photocathode. The image is intensified with a microchannel plate (MCP) image intensifier tube and recorded with a charge-coupled device (CCD) sensor that is part of a two dimensional solid state TV camera.[4] The streak camera/CCD system digitally records the streak camera image. The results are immediately ready for display on a video monitor, and for data processing by a digital computer. Figure 1 shows a typical streak camera/CCD system output displayed on video monitor and a line out of the intensity versus position profile displayed on the computer graphics terminal.

The optical fibers used in these tests were graded-index fibers made by Corning[5] and supplied by Siecor as their type 122 cable. We used samples taken from two different reels of cable. The graded-index core of these fibers is designed to minimize temporal dispersion. As shown in Figure 2, the fiber has a 62.5-µm diameter core surrounded by a 125-µm diameter cladding which is coated with a thin (6-µm) buffer layer of lacquer to preserve fiber strength and protect it from abrasion. We prepared the cable ends in the following manner. Several centimeters of cable jacket are removed, then several centimeters of fiber buffer are dissolved with acetone. Next the fiber is cleaved and the end is examined with a microscope to insure a clean cut. The cables are held in position with clamps placed around the cable jacket. The fiber ends are allowed to protrude from the jacket material so that the fiber end is in contact with air.

II. Measurements with 0.53-μm Light

Figure 3 shows a set of data recorded for 0.53-μm pulses transmitted through a 12-meter section of optical fiber. A 20-cm focal length lens focussed the laser energy onto the fiber. For this sequence of data, the focal point was adjusted across the end of the fiber to excite various core and cladding modes. For figures 3a and 3e, the energy is preferentially coupled into and propagated in the cladding. Since the index of refraction is lower in the cladding than in the core, the cladding propagated energy appears as a distinct prepulse arriving earlier than the core propagated energy. Figure 3 shows that the ratio of cladding propagated energy to core propagated energy is easily varied by adjusting the energy coupling into the fiber. For each focussing scheme, the simultaneously recorded laser pulse that was propagated along the air path is also shown. In each case, the normalized air pulse overlays the core propagated fiber pulse at 800 ps. For times earlier than 700 ps, where the cladding propagated pulse appears, there is no air pulse.

Figure 4a shows the results of uniformly illuminating the same optical fiber with collimated 0.53-μm laser pulse. In this case, the cladding propagated prepulse has an amplitude only 3% of the core propagated pulse. This is a factor of 100 less than the prepulse formed by preferentially focussing the energy into the cladding as in figures 3a and 3e.

The input end of this same cable was then prepared in such a way that cladding mode energy is removed from the fiber (mode stripping).

The buffer material was dissolved back 6-cm from the input end of the fiber with acetone and placed in a hypodermic needle filled with optical coupling grease. In this configuration, the input laser could not be focussed to generate a noticeable prepulse. (See figure 4b and 4c). The optical grease provides an effective means for stripping cladding mode energy from the fiber.

Six, 24, and 30 meter samples of fiber taken from a second reel of cable were also tested. For each length, no focussing scheme tried could produce the prepulse so easily obtained with the 12-meter sample. Typical data for the 6 and 24-m lengths of cable using collimated 0.53-μm light are shown in Figure 5. The pulse propagated through the 6-m cable accurately represents the pulse incident on the fiber as shown in figure 5a. However, the pulse propagated through the 24-m cable is broadened by 30 ps as shown in figure 5b. For this measurement the cable was loosely coiled (1-m dia) on an optical bench. The pulse broadening is substantially reduced by the use of mode stripping. Figure 5c shows the effect of mode stripping the output end only, and figure 5d the effect of mode stripping both the input and output end of the cable.

IV. Measurements with 1.06-μm Light

The measurements described for 0.53-μm light were repeated using 1.06-μm laser light. For the 6- and 30-meter lengths of the second fiber sample, no focussing position was found that produced a detectable cladding propagated prepulse. Figure 5e and 5f show data recorded using uniform fiber illumination with a collimated 1.06-μm laser beam. The pulse shows no detectable dispersion in the 6-meter cable. The longer cable does cause slight distortion of the leading edge of the pulse, but not as much as with 0.53-μm light.

For the 12-meter fiber sample, we could not excite and detect a distinct cladding mode prepulse. Figure 6 shows data recorded with the 1.06-μm laser beam focussed predominantly on the cladding area of the fiber with the 20-cm focal length lens. Some distortion of the pulse is noted with this focussing. A collimated beam into the 12-m cable is transmitted without detectable dispersion as shown in Figure 6b.

V. Discussion

Optical transmission characteristics (minimum bandwidth and maximum attenuation) and fiber physical data (core, cladding, and buffer diameters, and numerical aperature) are generally used to specify graded-index optical fibers. Similarly specified fibers can cause significantly different dispersion effects on short duration laser pulses being propagated through them. In the 6-m cable (sample #2), 40-ps 0.53-μm and 1.06-μm light pulses showed no significant temporal dispersion. But in the 12-m cable (sample #1) energy propagated in the fiber cladding causes noticeable pulse distortion. The cladding modes were much easier to excite and propagate at the shorter wavelength. The biggest problem in minimizing time dispersion in short fiber cables seems to be the coupling of laser energy into cladding modes rather than core modes. With a focussed beam, great care must be used to insure that the light excites only core modes and not cladding modes. Alignment is critical. Misalignment of 25 μm can result in preferential excitation of cladding modes rather than core modes.

In the 24- and 30-m cable, there is some distortion of the leading edge of the pulse at both wavelengths. This is probably due to imperfections and micro-bending which cause mode coupling between core and cladding as the energy propagates along the fiber. Using mode stripping at the cable ends helps to reduce the pulse distortion in cables 20- to 30-meters long.

VI. Conclusions

Laser pulses at 0.53 and 1.06 μm can be propagated through short (up to 30-m) lengths of graded-index optical fiber without significant temporal dispersion. We found, however, that energy propagation in cladding modes can cause significant pulse distortion. Energy injected directly into the cladding travels the length of the fiber faster than energy in the core forming an apparent prepulse. Time separation between prepulse and main pulse is proportional to the cable length. Energy injected into the fiber core can couple into cladding modes along the fiber and cause broadening on the front edge of the main pulse. It is important, therefore, to use care in the setup and characterization of the cable.

Two methods to reduce the chance of accidental excitation of cladding modes were demonstrated. Uniform illumination of the fiber end insures the cladding and core modes are excited in a ratio characteristic of the cable. Even for the 12-m sample in which we easily excited undesirable cladding modes, this technique reduced the prepulse to 3 percent of the desired core pulse. We also found that using a mode stripping technique at the fiber input eliminated the ability to preferentially excite cladding modes.

Fiber optic technology has experienced significant growth and change over the past few years. Recently the industry has standardized on the 50-μm diameter core for graded-index fibers. When working with fast pulse propagation through this type of cable it is important for the user to realize that although cables may have identical specifications, the temporal distortion may vary substantially from setup to setup and from fiber to fiber. When accurate temporal transmission over short cable is required, a pulse propagated through the cable should be compared with the pulse incident on the cable. This technique can clearly demonstrate the quality of temporal transmission.

References

1. Laser Program Annual Report - 1979, Lawrence Livermore National Laboratory, Livermore, California, UCRL-50021-79 (1980), pp. 5-29 to 5-32.
2. Laser Program Annual Report - 1977, Lawrence Livermore National Laboratory, Livermore, California, UCRL-50021-77 (1978) pp. 3-42 to 3-45. Laser Program Annual Report - 1976, UCRL-50021-76 (1977), pp. 3-55 to 3-60. Laser Program Annual Report - 1975, UCRL-50021-75 (1976), pp. 399-401.
3. Optical Fiber Telecommunications, S.E. Miller and A.G. Chynoweth, Ed; Academic Press, N.Y. (1979).
4. Laser Program Annual Report - 1979, Lawrence Livermore National Laboratory, Livermore, California, UCRL-50021-79 (1980), pp. 5-17 to 5-21.
5. Reference to a company or product names does not imply approval or recommendation of the product by the University of California or the U.S. Department of Energy to the exclusion of others that may be suitable.

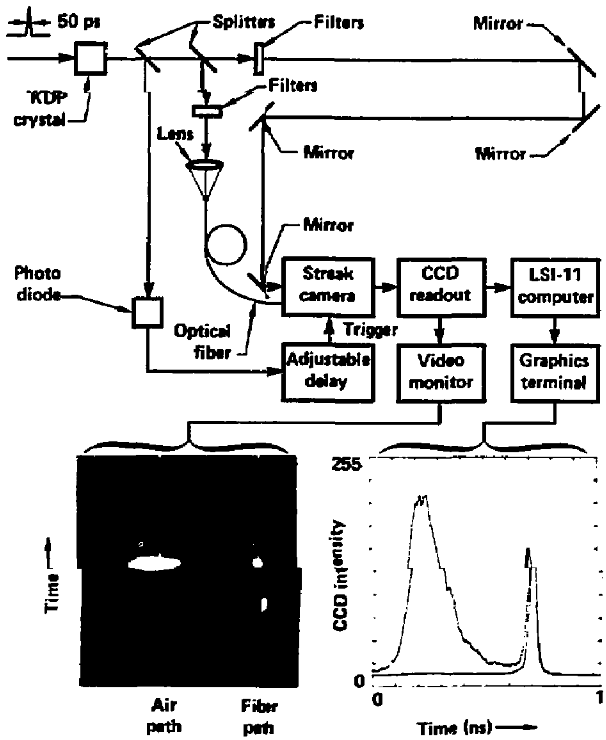

Fig. 1 Experimental setup. The streak camera simultaneously records the laser pulse incident on the optical fiber and the laser pulse transmitted through the fiber. The CCD readout provides rapid analysis of the streak camera image. The dashed lines show where the two graphics terminal lineouts are taken. The lineout of the fiber transmitted pulse shows two distinct peaks. The lineout of the incident (air path) pulse has a peak at 700 ps which overlays the second fiber pulse.

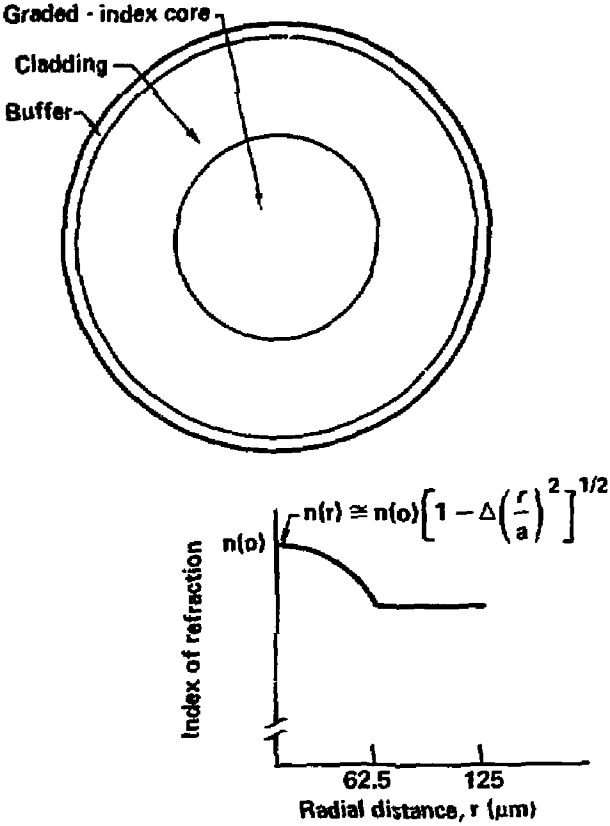

Fig. 2 Graded index optical fiber. (a) Fiber cross section. (b) Index of refraction versus radius. For the fibers tested, $n(o) \sim 1.52$, $\Delta \sim 0.018$, $a \sim 62.5$ μm, and $\alpha \sim 2.0$. The index of refraction in the cladding is about 1.50.

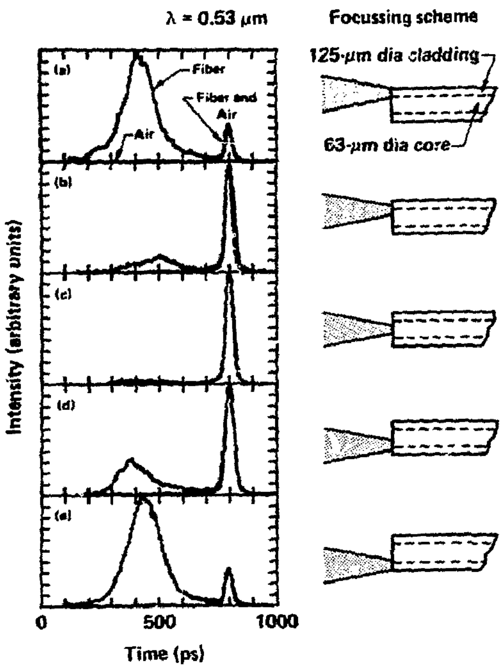

Fig. 3 50-ps, 0.53-μm laser pulses transmitted through 12-m of optical fiber (sample #1) compared with laser pulse at the input to the fiber for various focussing schemes. The air propagated pulse overlays the core propagated fiber pulse at 800 ps on each trace. The pulse at 400 ps on each trace is due to laser energy propagated by fiber cladding modes. The air path trace at 400 ps is at the base line. This sequence of data shows that the ratio of energy propagated in cladding modes to energy propagated in core modes is a strong function of the energy coupling into the fiber.

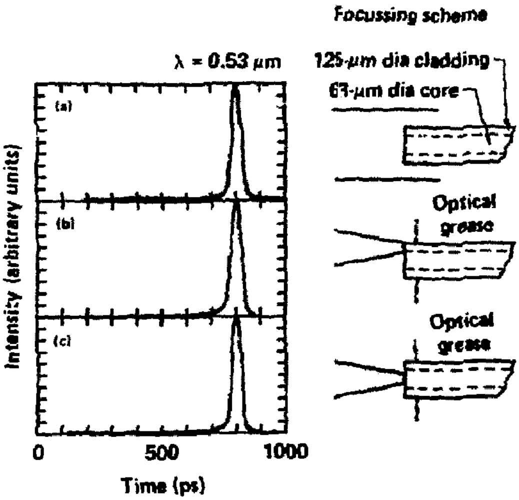

Fig. 4 50-ps, 0.53-μm laser pulses transmitted through 1z-m of optical fiber (sample #1) compared with laser pulse at the input to the fiber. The air propagated pulse overlays the core propagated fiber pulse at 800 ps on each trace. (a) Use of collimated beam reduces unwanted cladding propagated energy at 400 ps to 3% of the core propagated pulse (compare with figure 3). Use of mode stripping reduced cladding propagated energy to less than 1% of core propagated energy. The trace in (b) with energy focussed on the cladding required 100 times the laser energy to produce the same amplitude as the pulse in (c).

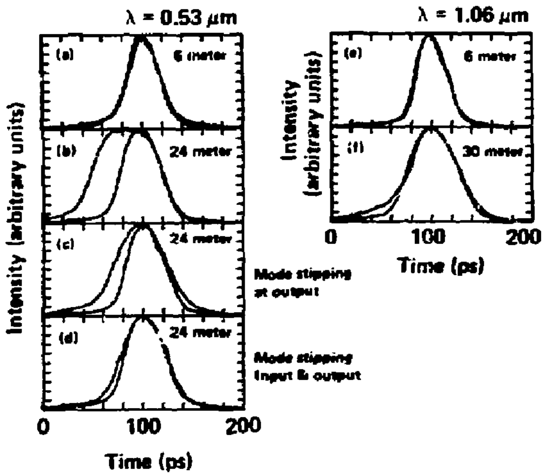

Fig. 5 0.53- and 1.06-μm laser pulses transmitted through 6, 24, and 30 m of optical fiber (sample #2) compared with the laser pulse at the input to the fiber. For each trace, the laser pulse was collimated to provide uniform excitation of the fiber core and cladding modes. (a) 40-ps, 0.53-μm pulse propagated through 6-m cable looks almost identical to input pulse. (b) 45-ps, 0.53-μm pulse propagated through 24-m cable shows 30 ps broadening on leading edge of pulse. (c&d) Mode stripping significantly reduces the broadening of the 40-ps, 0.53-μm laser pulses by the 24-m cable. (e) 40-ps, 1.06-μm pulse propagated through 6-m of cable looks almost identical to the input pulse. (f) 55-ps, 1.06-μm pulse propagated through 30-m cable shows slight distortion on the leading edge of the pulse.

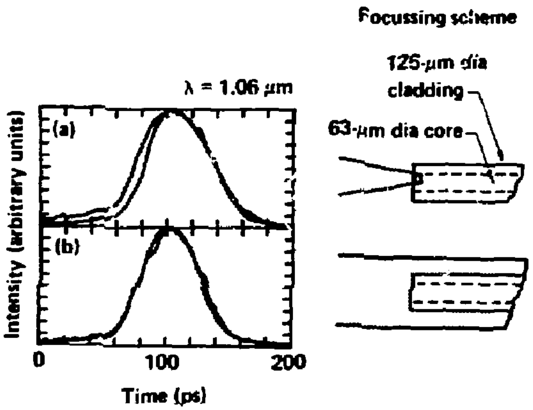

Fig. 6 1.06-μm laser pulses transmitted through 12-m of optical fiber (sample #1) compared with laser pulse at input to fiber. (a) Focussed 60-ps, 1.06-μm pulse shows 10-ps broadening of the leading edge. (b) Collimated 55-ps, 1.06-μm pulse looks almost identical to input pulse.